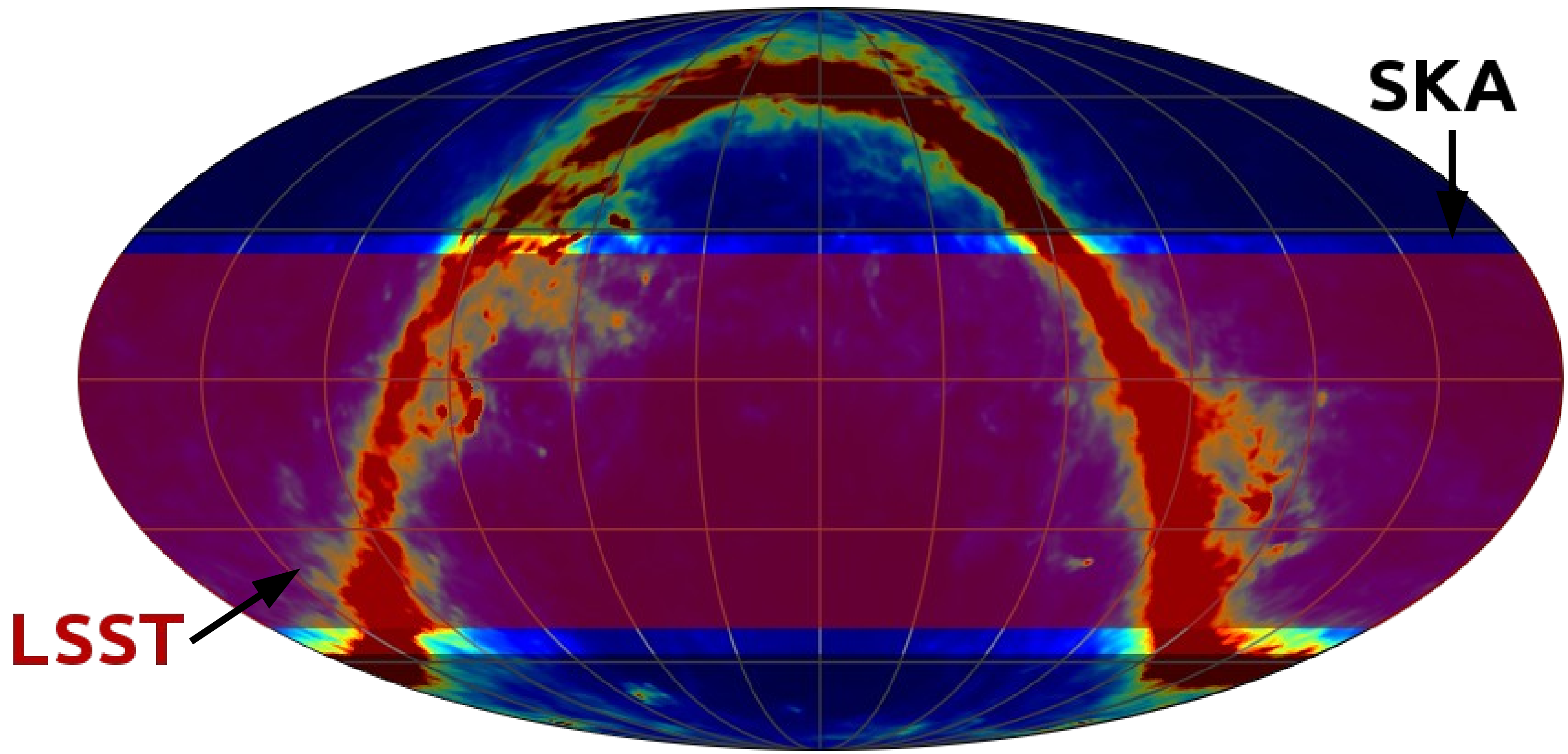
SKA-LSST synergies: I) Intensity mapping and large scales

David Alonso – Oxford Astrophysics



Cross-correlation spectacular - BNL, 2016

Naming convention

1 SKA, 2 Davids

≠

Intensity mapping & large scales

David Alonso, Oxford

Pronunciation: Daa - beed

Galaxy clustering and lensing

David Bacon, ICG Portsmouth

Pronunciation: Day-vid

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Add a lisp for a nice Madrid accent!

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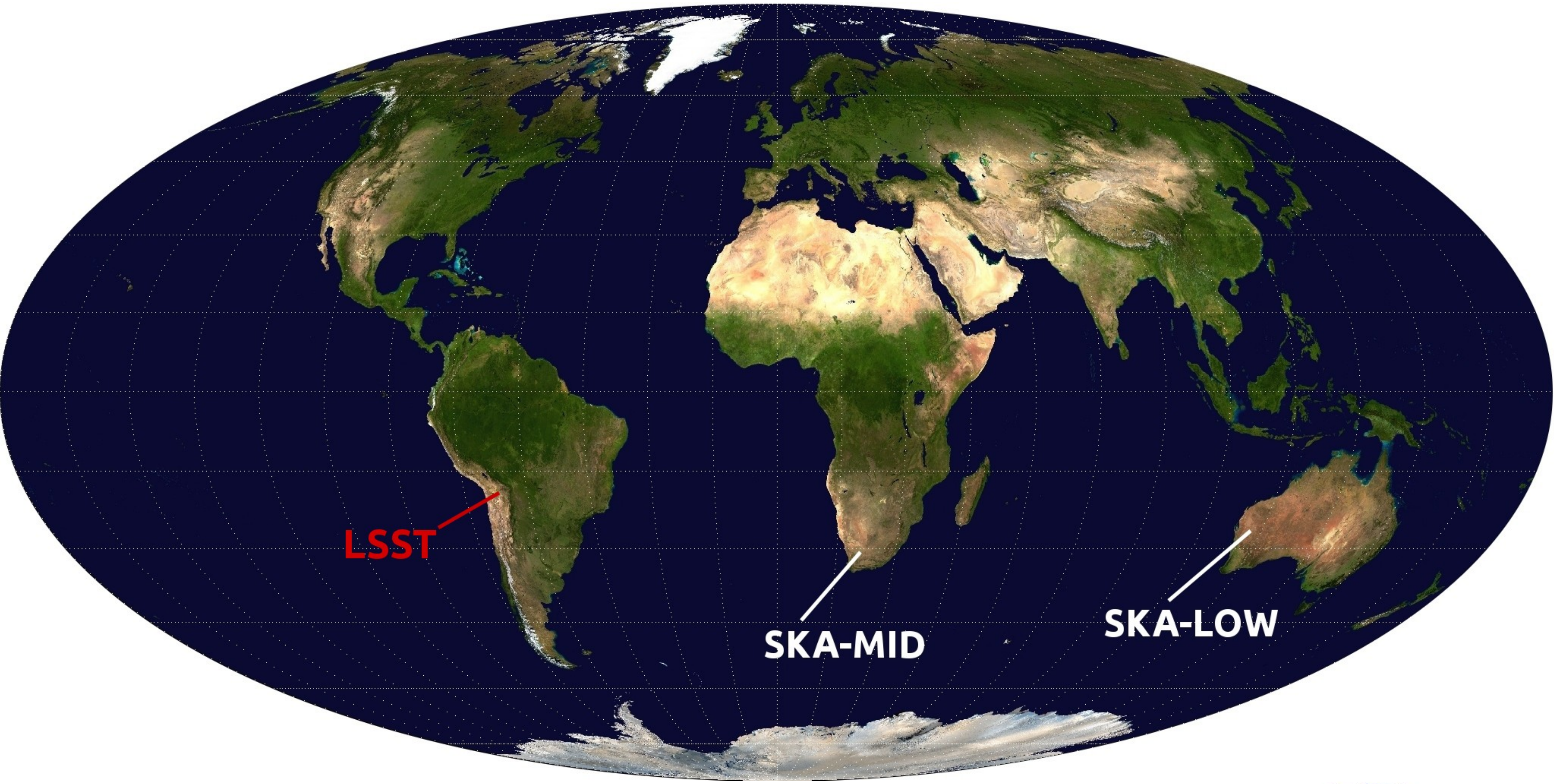
LSST & SKA

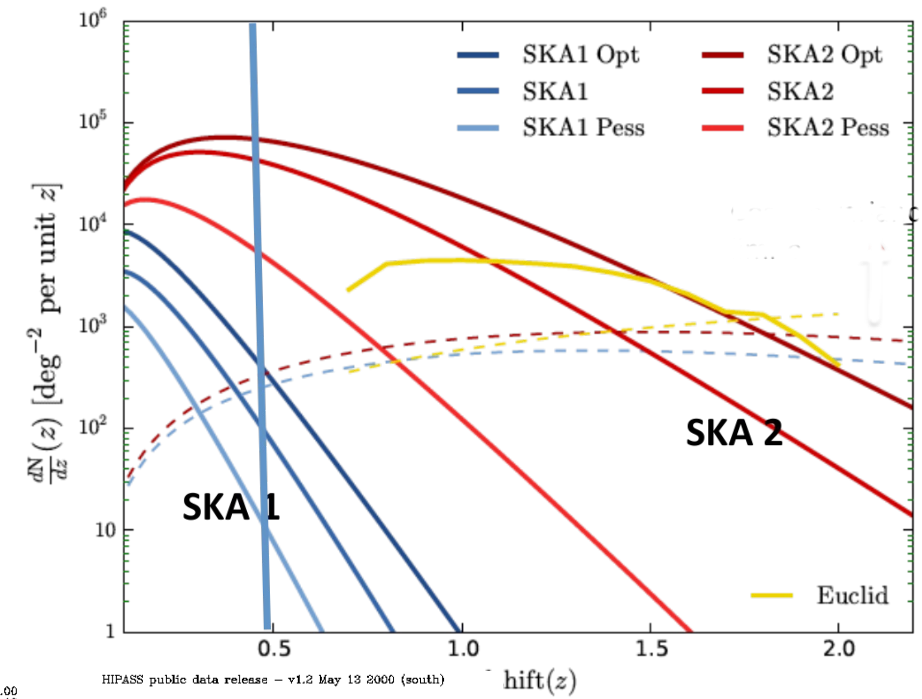


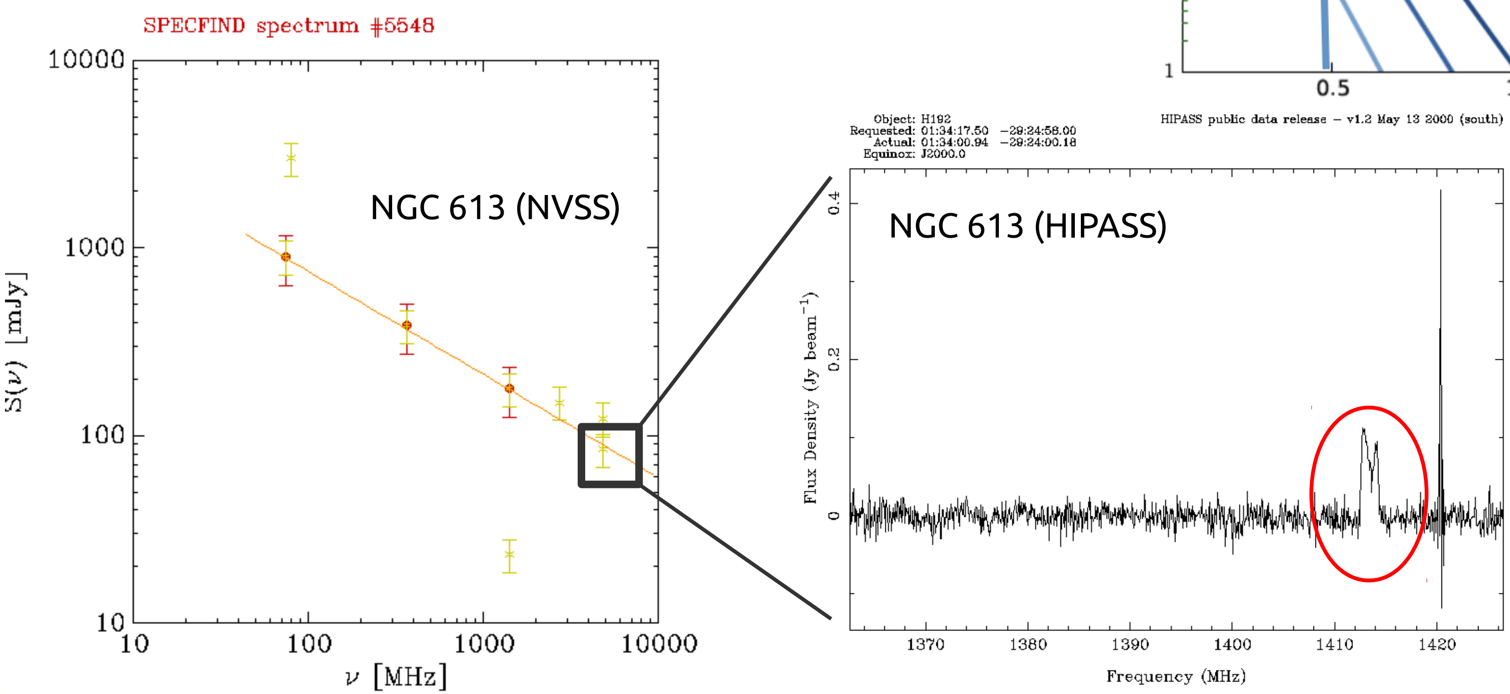
1. The SKA

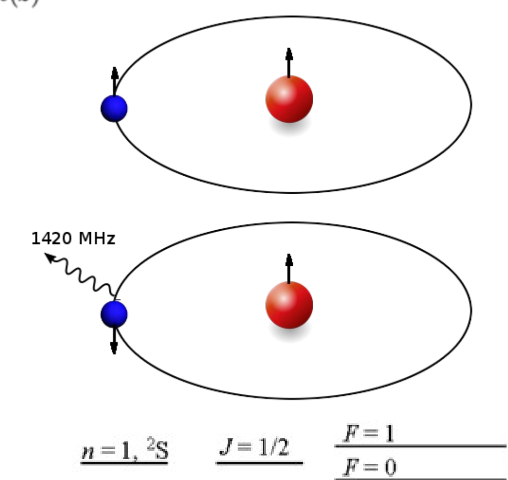
Cosmological radio signals

The astrophysical radio spectrum

- Characterized by featureless continuum emission (e.g. synchrotron).
- Few radio lines. Mainly neutral hydrogen (HI).
- Costly to measure for individual sources.



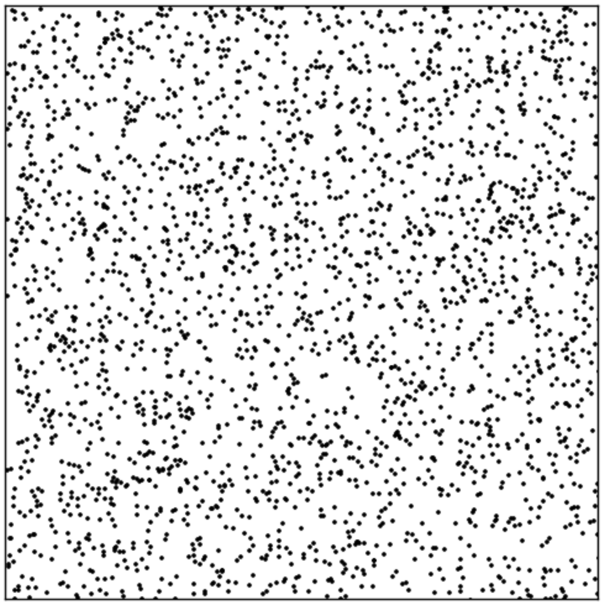


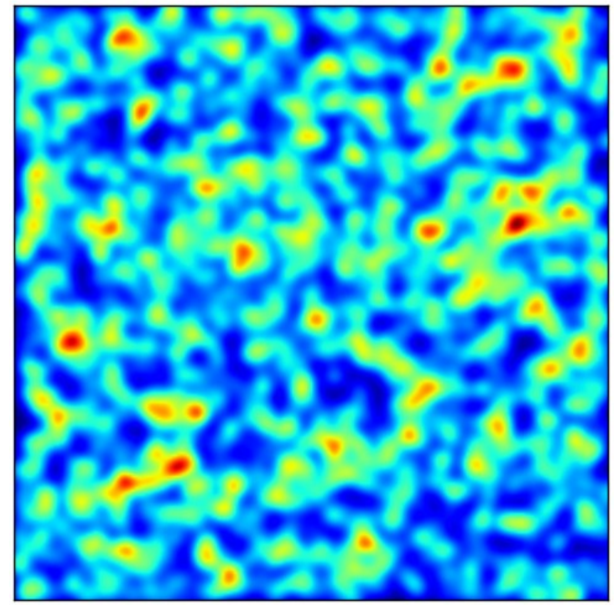


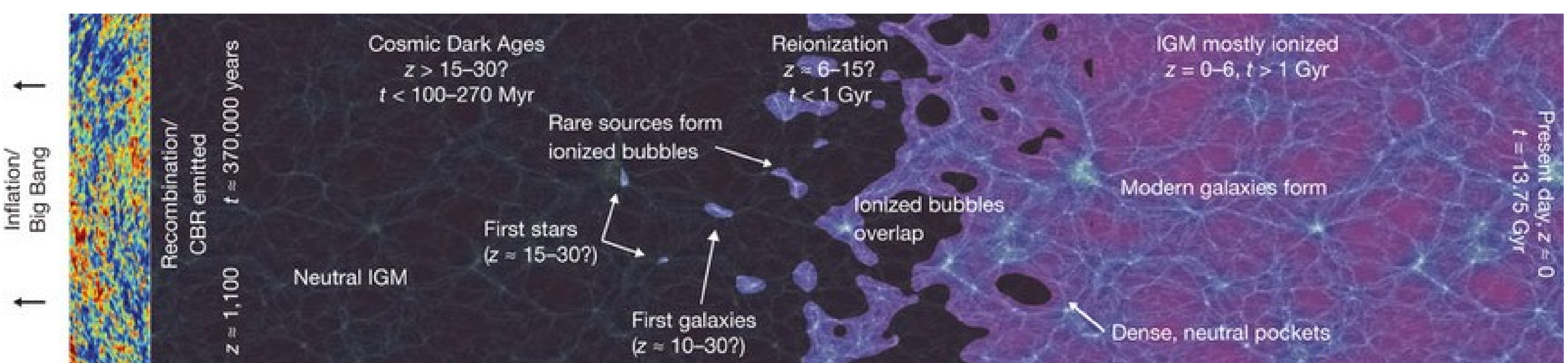
HI intensity mapping

- Large pixels: joint emission from multiple galaxies instead of resolving them.
- We only care about large scales
- “Cheap” way to observe large volumes

Battye, Davies & Weller, 2004
Masui et al. 1208.0331





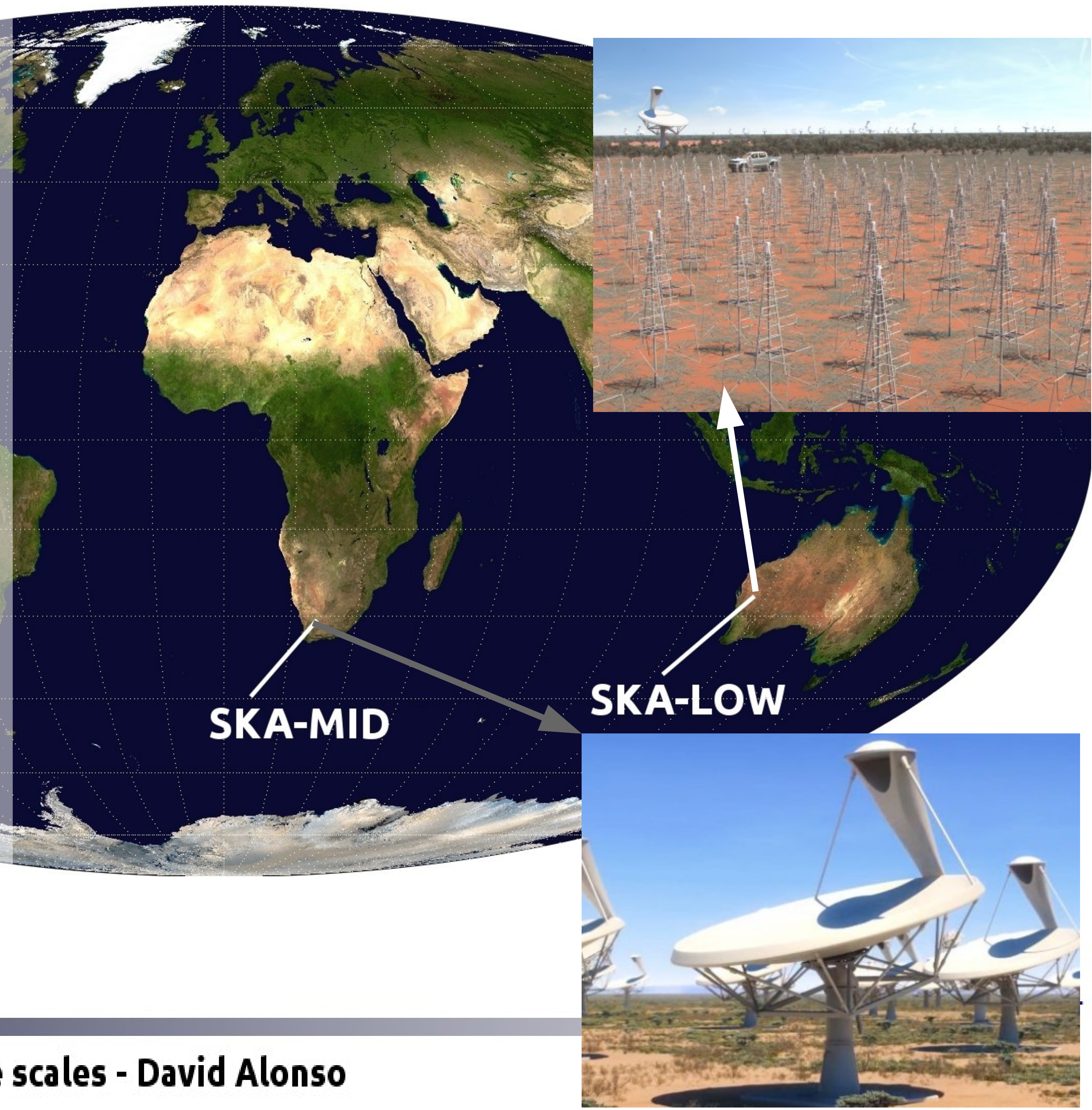


Oxford Physics

SKA

Two experiments:
- SKA-LOW: 50-350 MHz
- SKA-MID: 350 MHz – 14 GHz

Many science cases:
- Continuum survey: no z, many sources
- Weak lensing (with the above)
- HI survey: good z, few sources
- HI intensity mapping (z<3)
- EoR (z>3)
- Non-cosmological (e.g. pulsars)

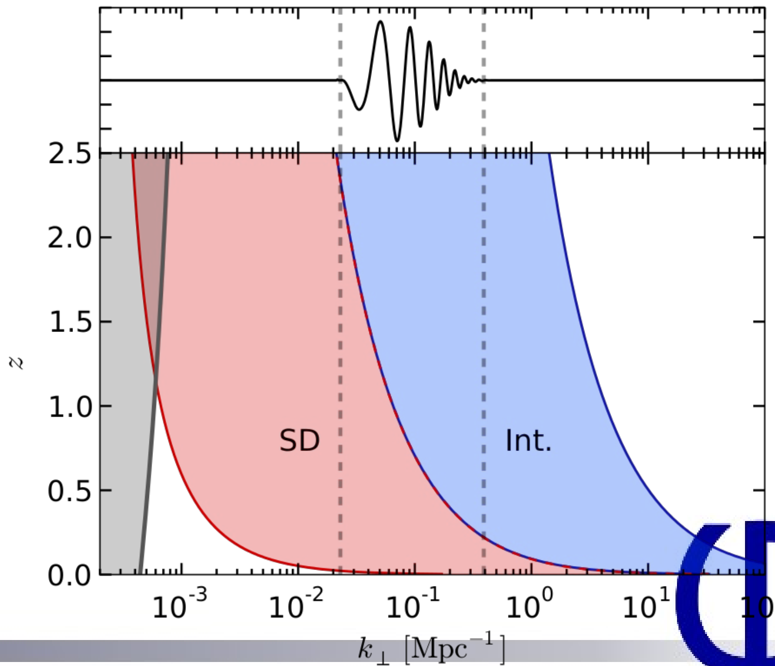


Maartens et al. 1501.04076

Intensity mapping with the SKA

- Baselines not small enough to cover BAO scales in interferometric mode.
- SKA1-MID will be used as a multi-single-dish experiment.
- Save interferometer data for calibration.
- Proposal to provide calibrated auto-correlations has been approved by the SKA office.
- SKA1 survey: 30K sq-deg, 10K hours, 350-1050 MHz.
- KAT7 (7) → MeerKAT (64) → SKA1 (197)

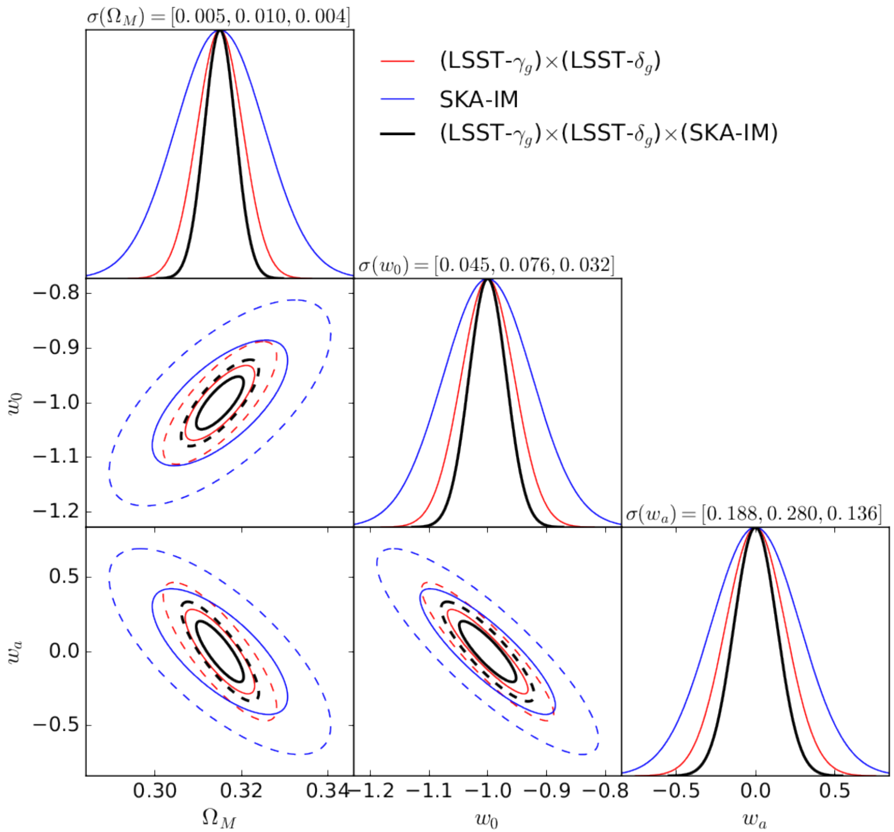
Possible survey overlapping with DES!

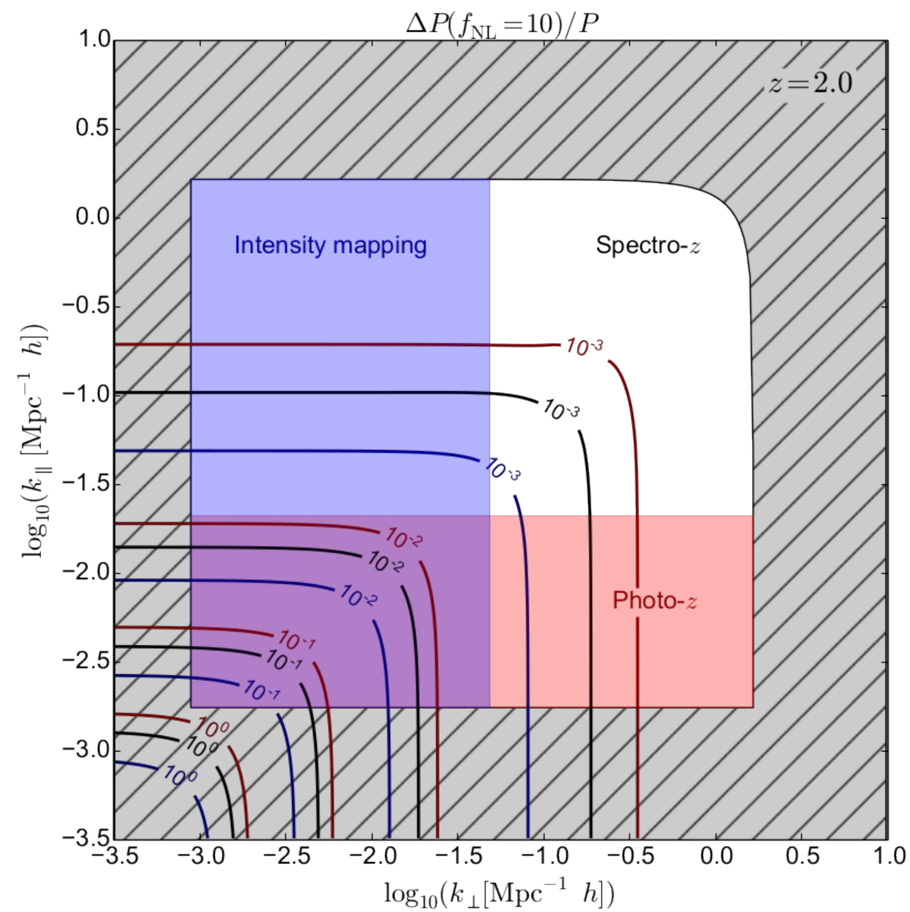


Santos et al. 1501.03989
Bull et al. 1405.1452
DA et al. 1405.1751, 1409.8667

2. Combining SKA1-IM and LSST

1 Combined cosmological constraints

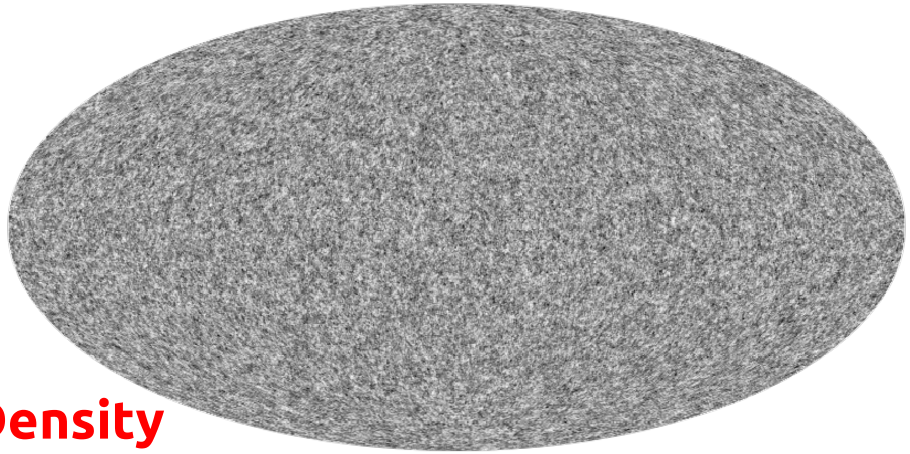




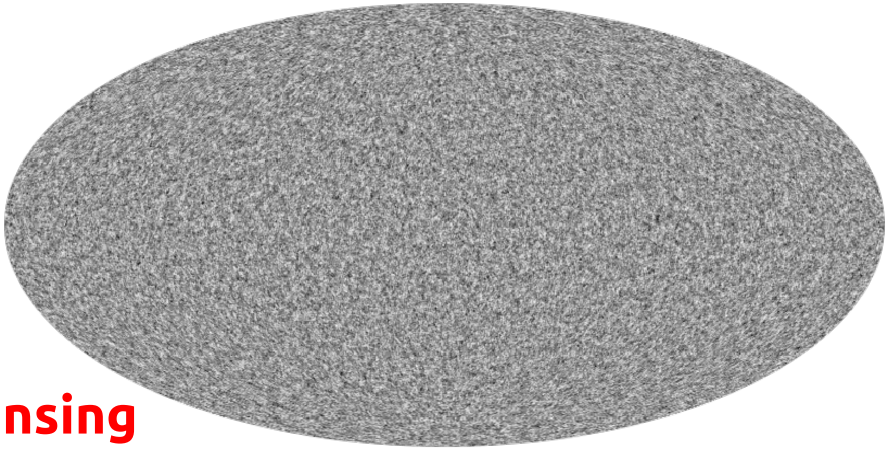
- Complementary coverage of scales.
- Complementary tracer properties (e.g. bias, magnification).

Bacon et al. 1501.03977
DA, P. Ferreira, M. Jarvis (in prep.)

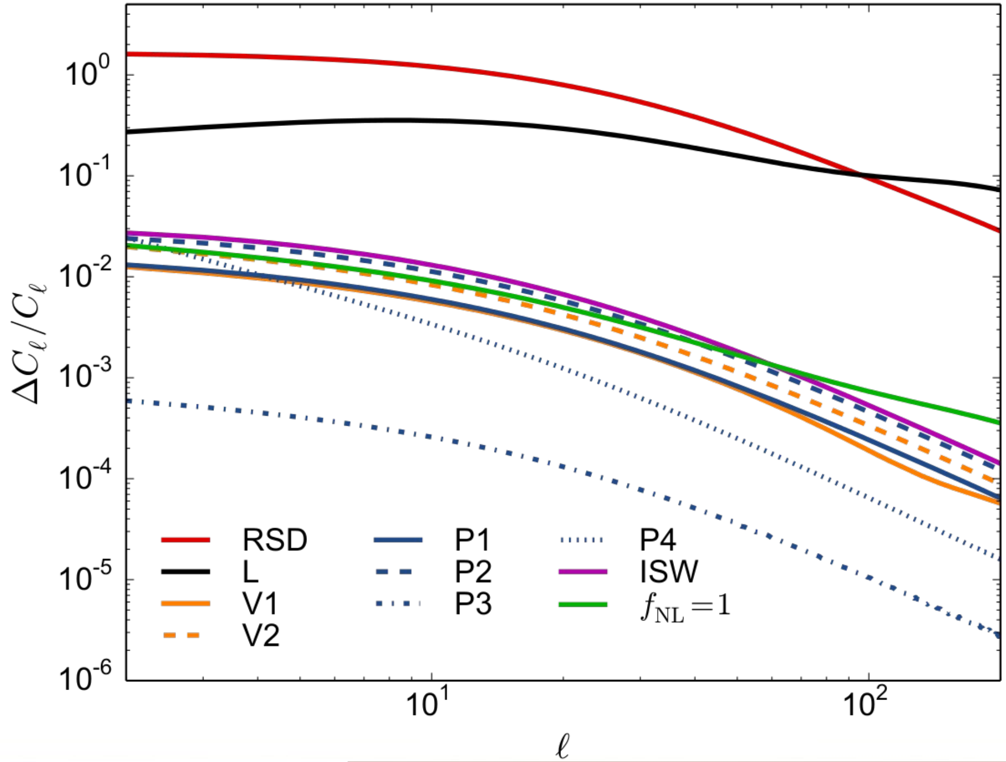
Ultralarge-scale observables

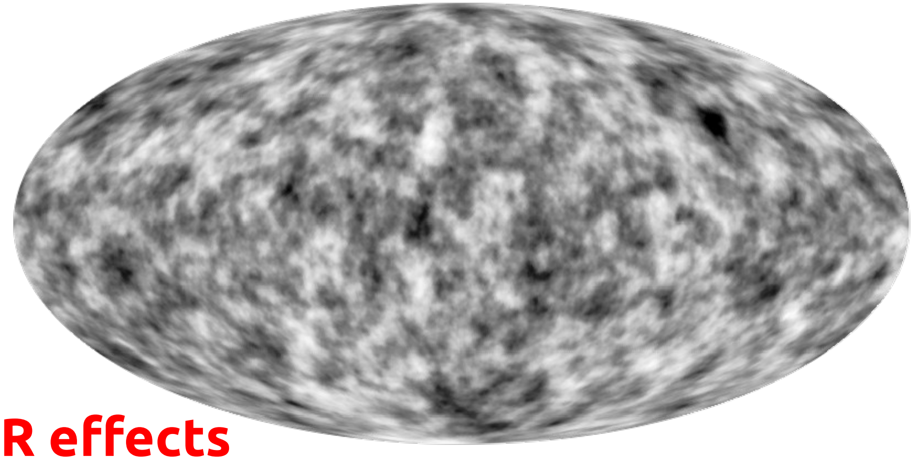


Density



Lensing





GR effects

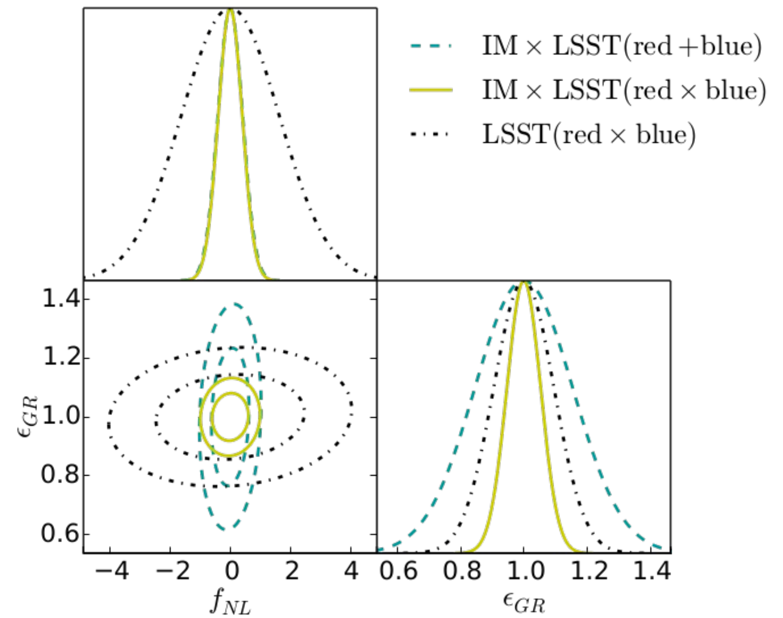
Challinor and Lewis, 1105.5292
Bonvin and Durrer, 1105.5280

Ultralarge-scale observables

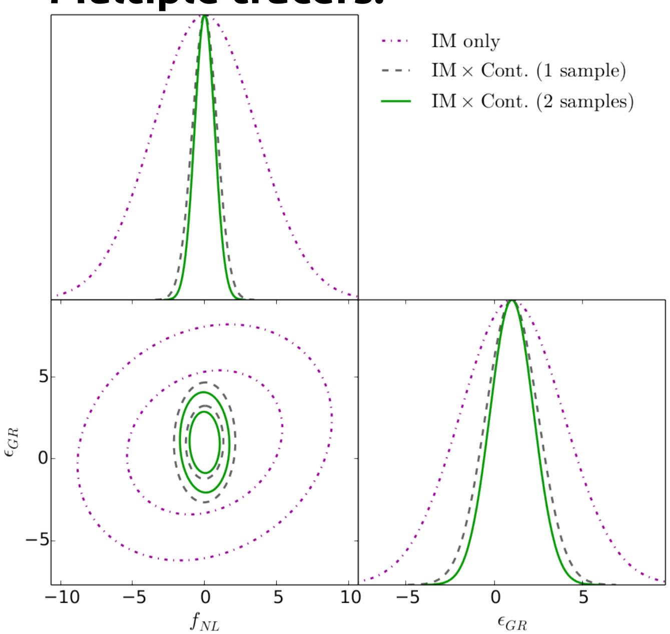
Single tracers:

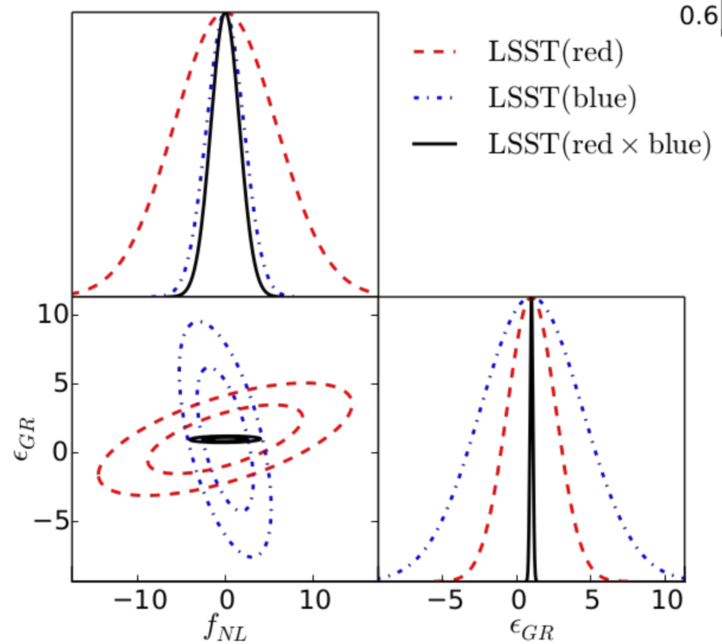
D.A. et al. 1507.03550

Experiment	$\sigma(f_{\rm NL})$	$\sigma(\epsilon_{\rm GR}$
Intensity mapping (SKA1-MID)	3.01	2.75
Continuum survey ($S_{\rm cut} = 1\mu Jy$)	11.8	17.1
Spectroscopic survey (Euclid)	6.64	2.57
Photometric survey (LSST)	1.71	2.33



Multiple tracers:





SKA: IM x cont. → σ(fNL)~0.8.

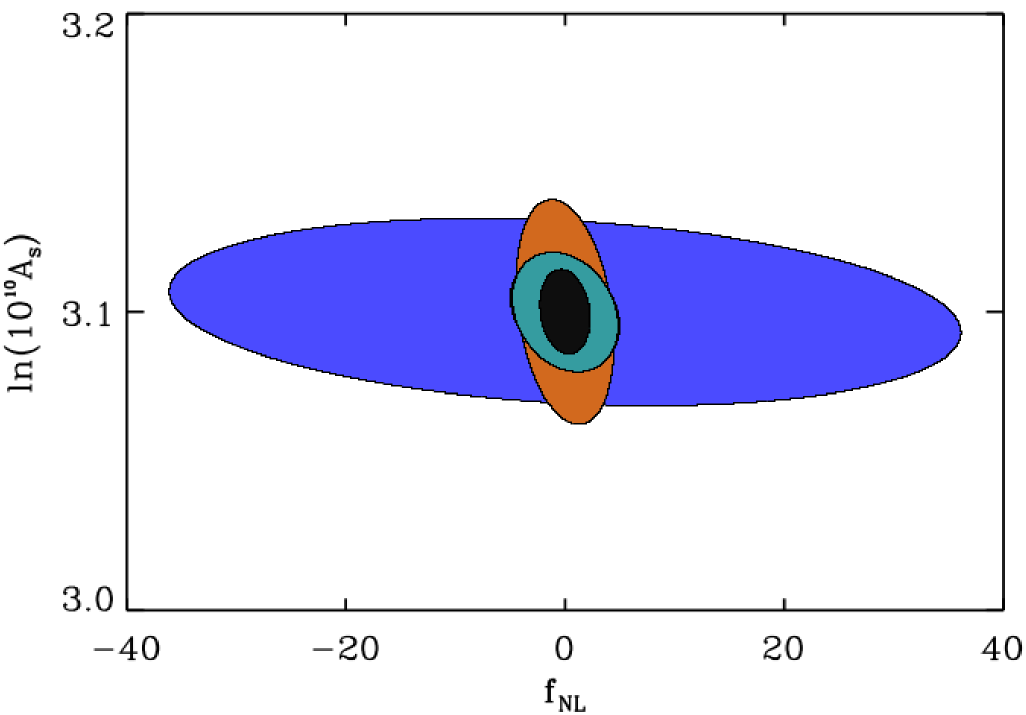
LSST: 5-10 σ detection of GR effects.

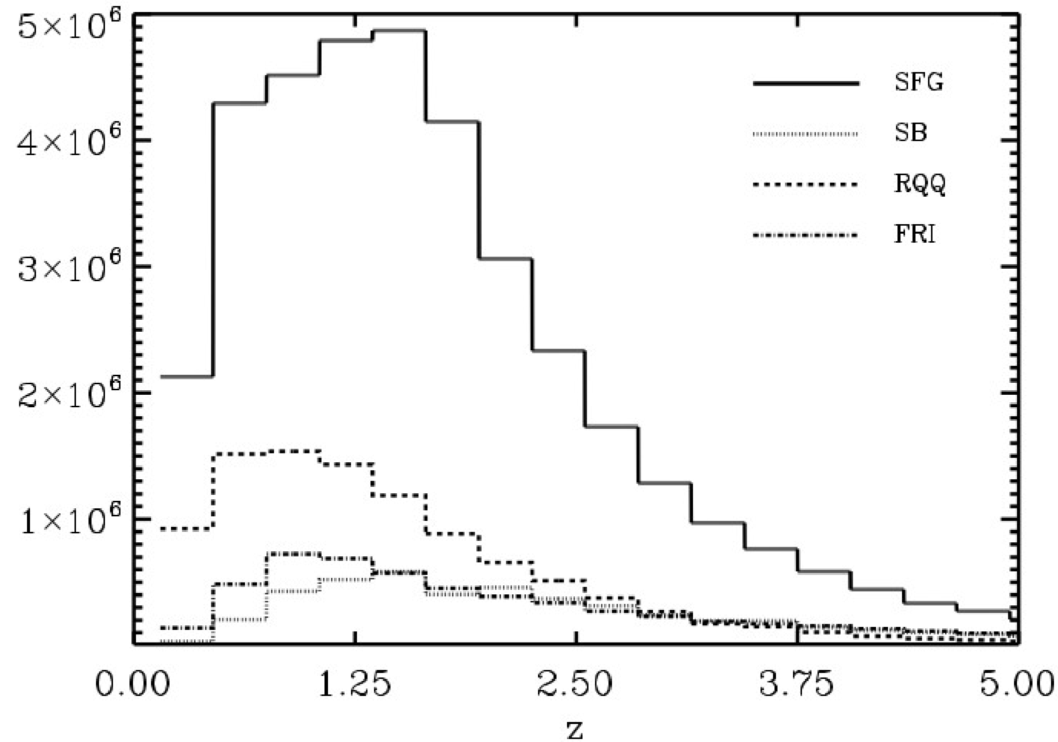
LSST x SKA

- IM and photo-z are complementary.
- Major improvement in both cases. x4 in $f_{\rm NL}$
- 10-20 σ detection of GR effects.

Oxford Physics

Ultralarge-scale observables



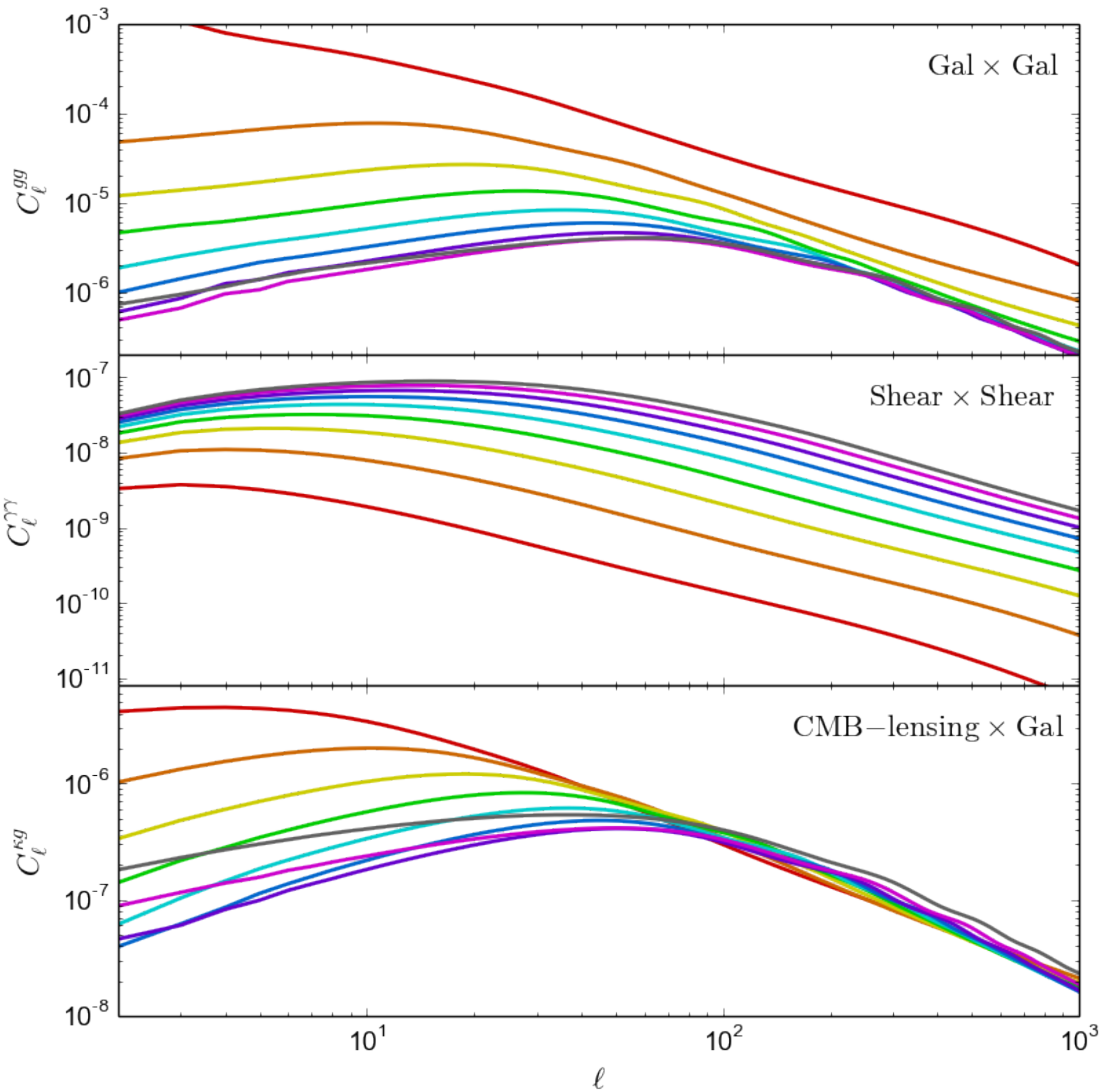


Ferramacho et al. 1402.2290

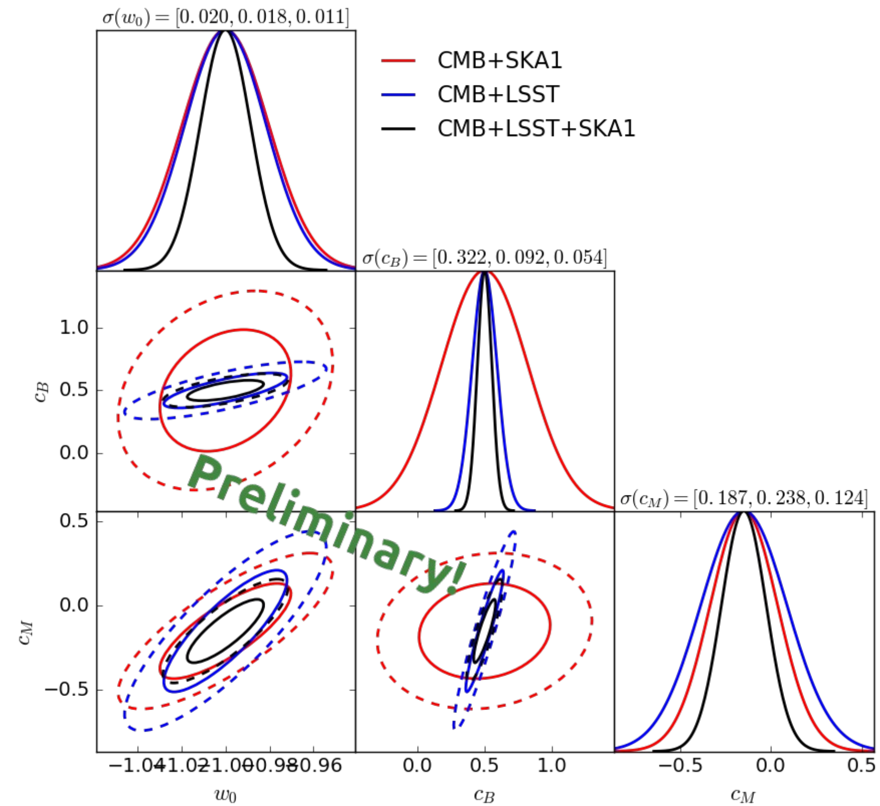
Continuum survey only:

- Advantages:
  - Enormous volumes
  - Large number of distinct tracers, with different clustering bias
- Disadvantages:
  - Difficult to separate all tracers with radio data alone
  - No redshifts → no tomography
- Both disadvantages can be cured in cross-correlation with LSST.

Constraining modified gravity

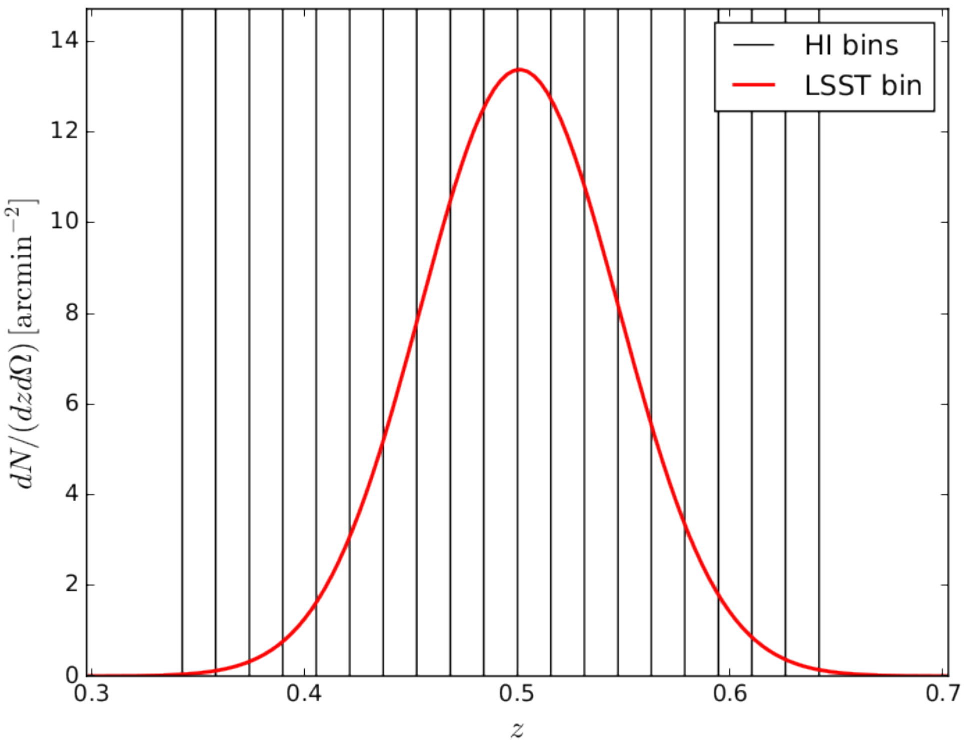


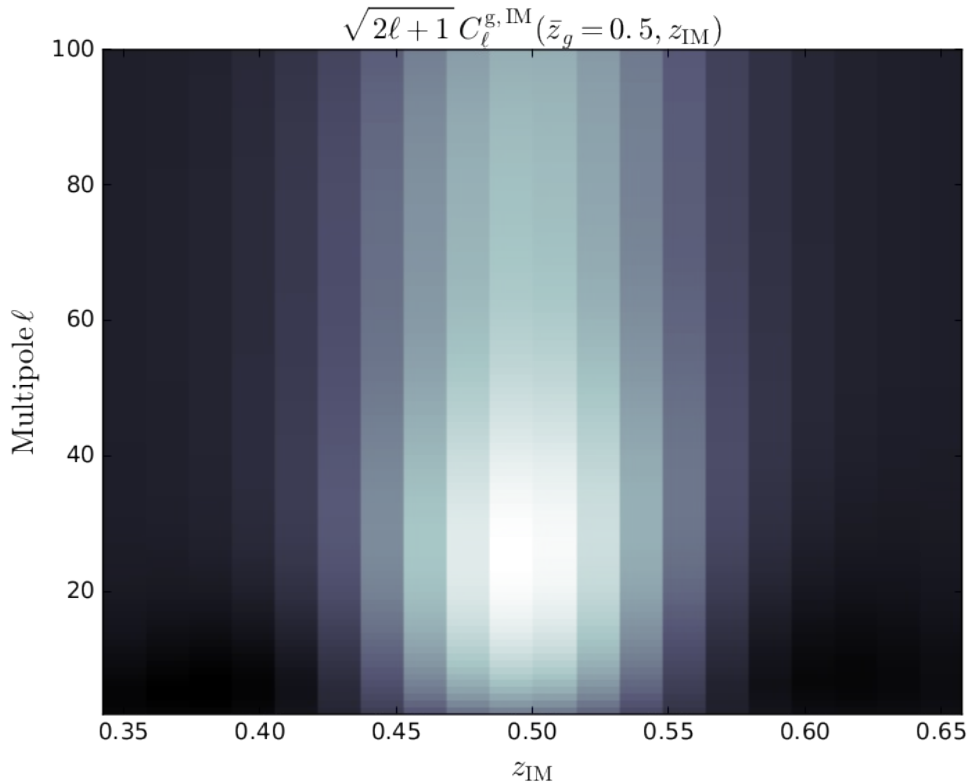
DA, P. Ferreira, E. Bellini, M Zumalacarregui (in prep.)



- Concept: throw in all tracers (and x-corrs!)
  - Galaxy clustering (LSST, blue and red)
  - Galaxy shear (LSST, gold sample)
  - Intensity mapping (SKA-1, 200 bins)
  - CMB primary (Planck)
  - CMB lensing (AdvACT)
- ~10x improvement over current constraints. (Bellini et al. 1509.07816)

2 Reducing photo-z systematics





Clustering redshifts:

- Idea: reconstruct photo-z distribution using cross-correlations with spectro-z
- Cross correlate photo-z bin with thin spectro-z bins.
- The amplitude of the cross-correlation traces the shape of the photo-z distribution.
- IM could work just as well!

Matthews & Newman, 1003.0687
Ménard et al. 1303.4722
DA, P. Ferreira, M. Jarvis (in prep.)

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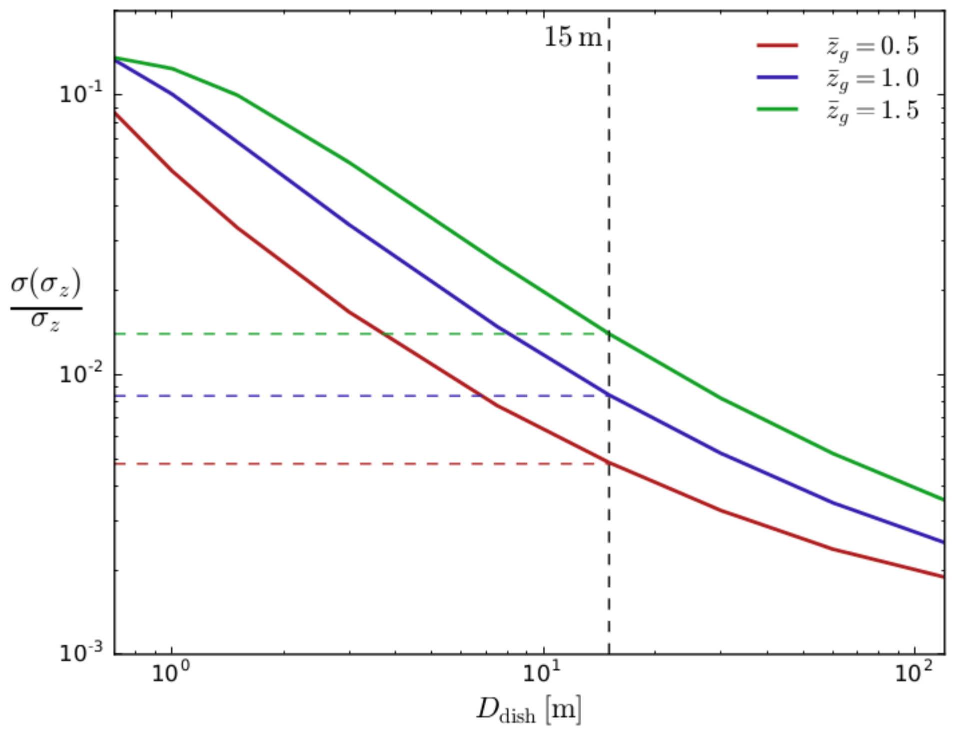

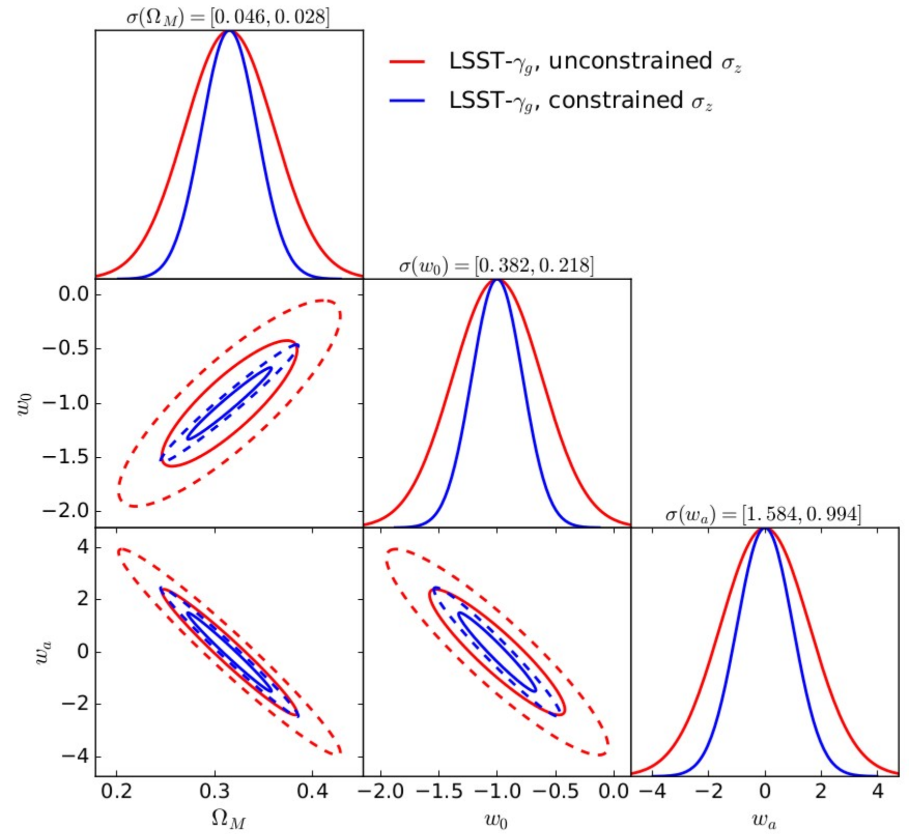

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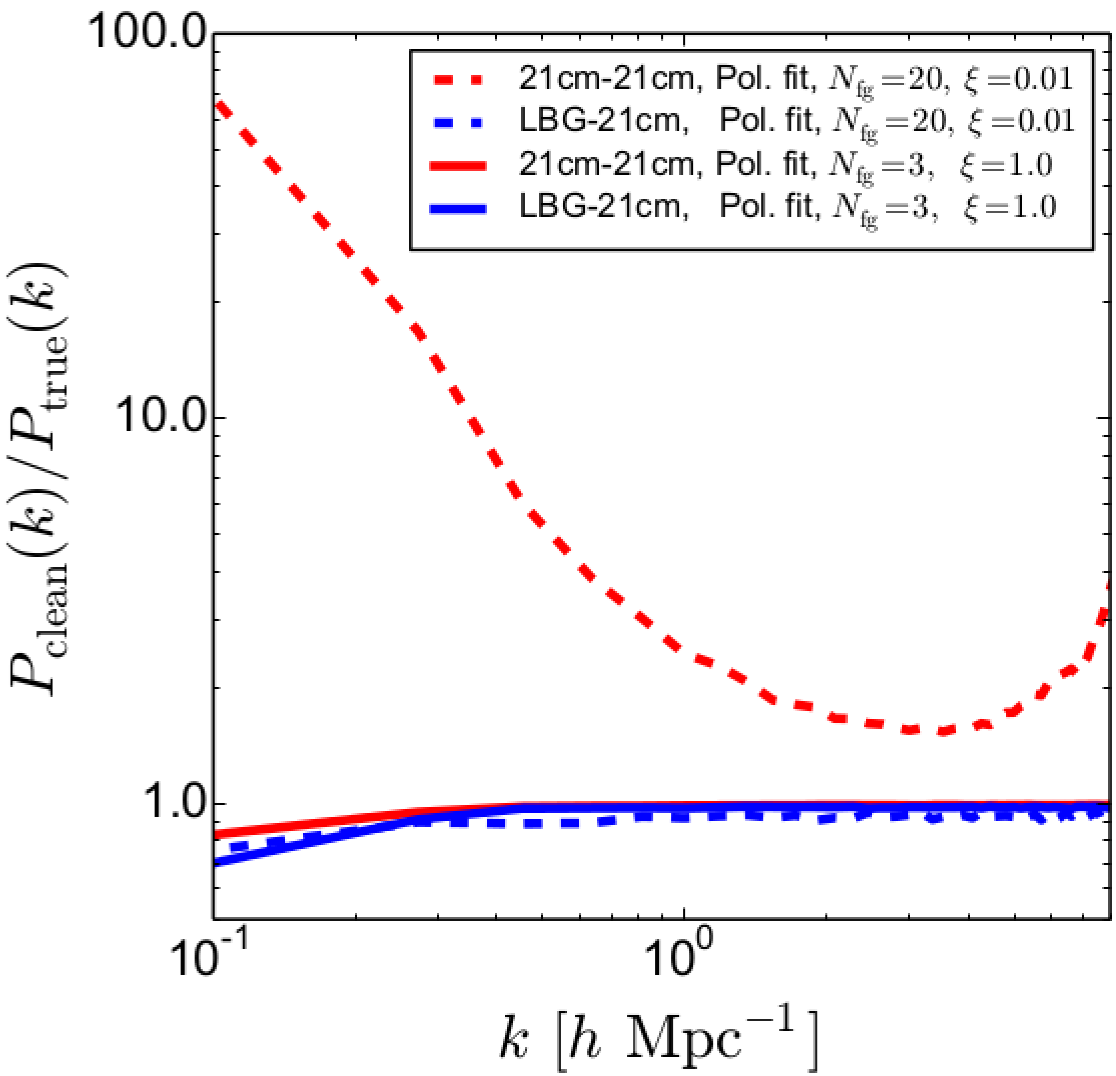
DA, P. Ferreira, M. Jarvis (in prep.)

3 Reducing foreground systematics



- Badly behaved foregrounds could be impossible to subtract.
- E.g. leaked polarized synchrotron.
- Foregrounds cancel out in cross-correlation.
- This was used to make 1st detection of IM signal (Masui et al. 1208.0331)
- Not yet done with photo-z surveys.

Villaescusa-Navarro et al. 1410.7393

4 Bayesian clustering analyses

General motivation: use **ALL** information to measure redshifts

$$\mathbf{z} \leftarrow p(\mathbf{z}|\mathbf{m}, \hat{\mathbf{n}}, \delta_{\rm HI})$$

magnitude
s

angular
positions

HI density

Jointly sample the underlying density distribution.

$$\{\mathbf{z}, \delta\} \leftarrow p(\mathbf{z}, \delta|\mathbf{m}, \hat{\mathbf{n}}, \delta_{\rm HI})$$

Can be done in a Gibbs-sampling way:

redshifts sampled individually

$$\mathbf{z}_{n+1} \leftarrow p(\mathbf{z}|\mathbf{m}, \hat{\mathbf{n}}, \cancel{\delta_{\rm HI}}, \delta_n) = \prod_g p(z^g|m^g)p(z|\delta_n(\hat{n}^g))$$

$$\delta_{n+1} \leftarrow p(\delta|\mathbf{z}_{n+1}, \cancel{\mathbf{m}}, \hat{\mathbf{n}}, \delta_{\rm HI}) = p(\delta|\delta_g(\mathbf{z}_{n+1}, \hat{\mathbf{n}}), \delta_{\rm HI})$$

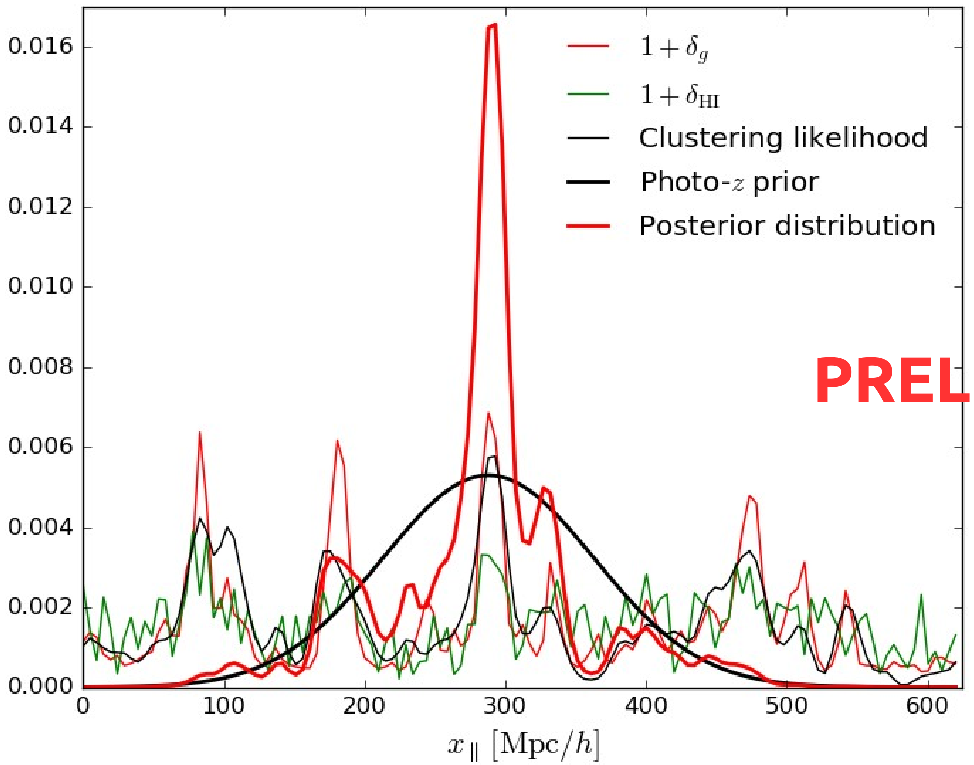
Jasche & Wandelt 1106.2757

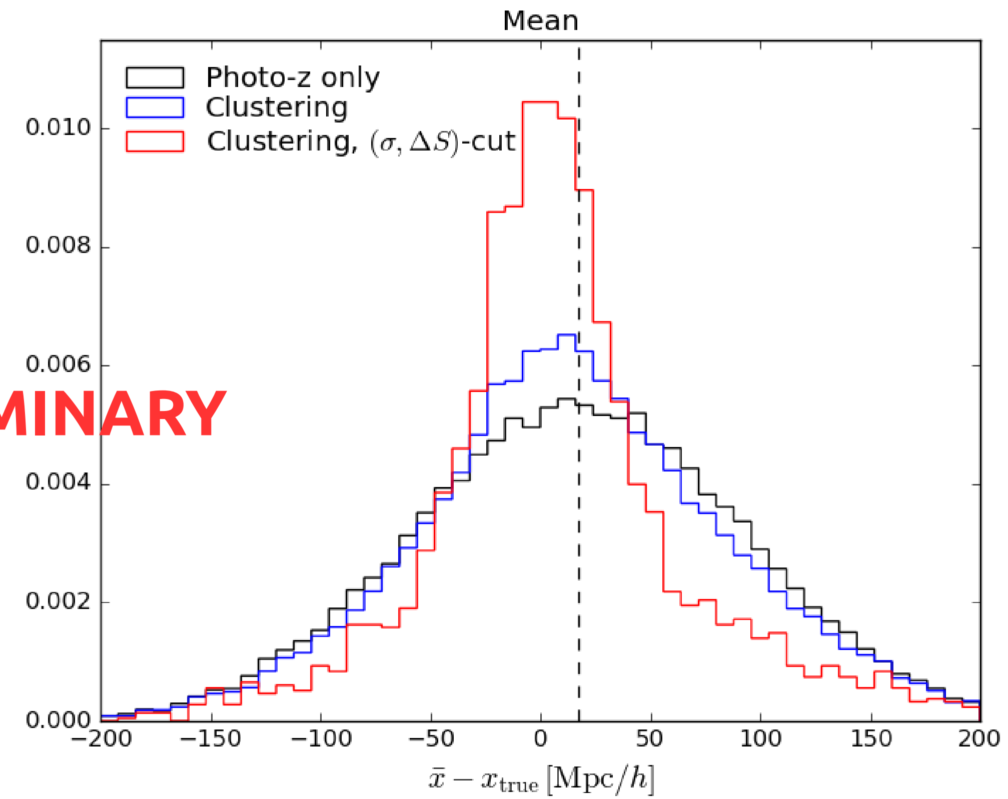
Galaxy overdensity in the (n+1)-th realization

DA, P. Ferreira, M. Jarvis (in prep.)

4 Bayesian clustering analyses

DA, P. Ferreira, M. Jarvis (in prep.)

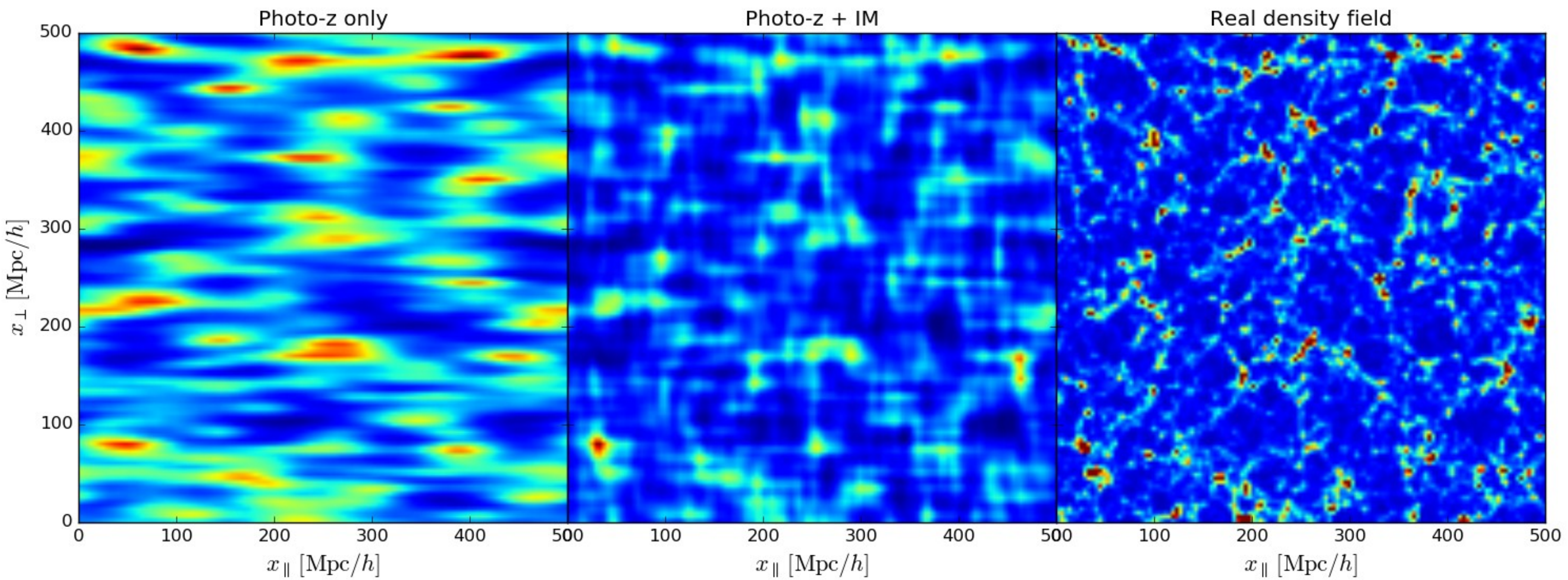




PRELIMINARY

- The posterior distributions are a lot more informative.
- On average, reduced photo-z uncertainties (>10%)
- On high-density regions, σ_z reduced by a factor of ~10
- Clean sample can be selected:
  - ~30% better photo-z's
  - Impervious to photo-z bias
- Improved redshift usable for non-clustering analyses (e.g. SNe?)

4 Bayesian clustering analyses



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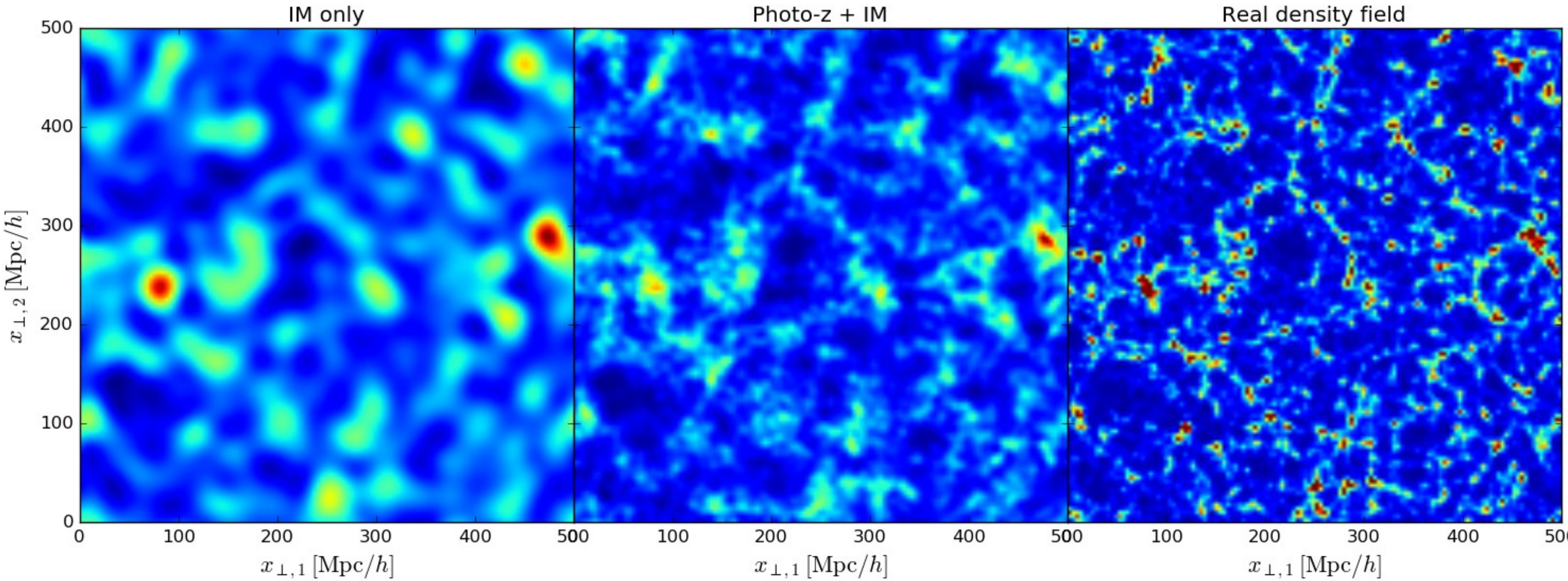
4 Bayesian clustering analyses



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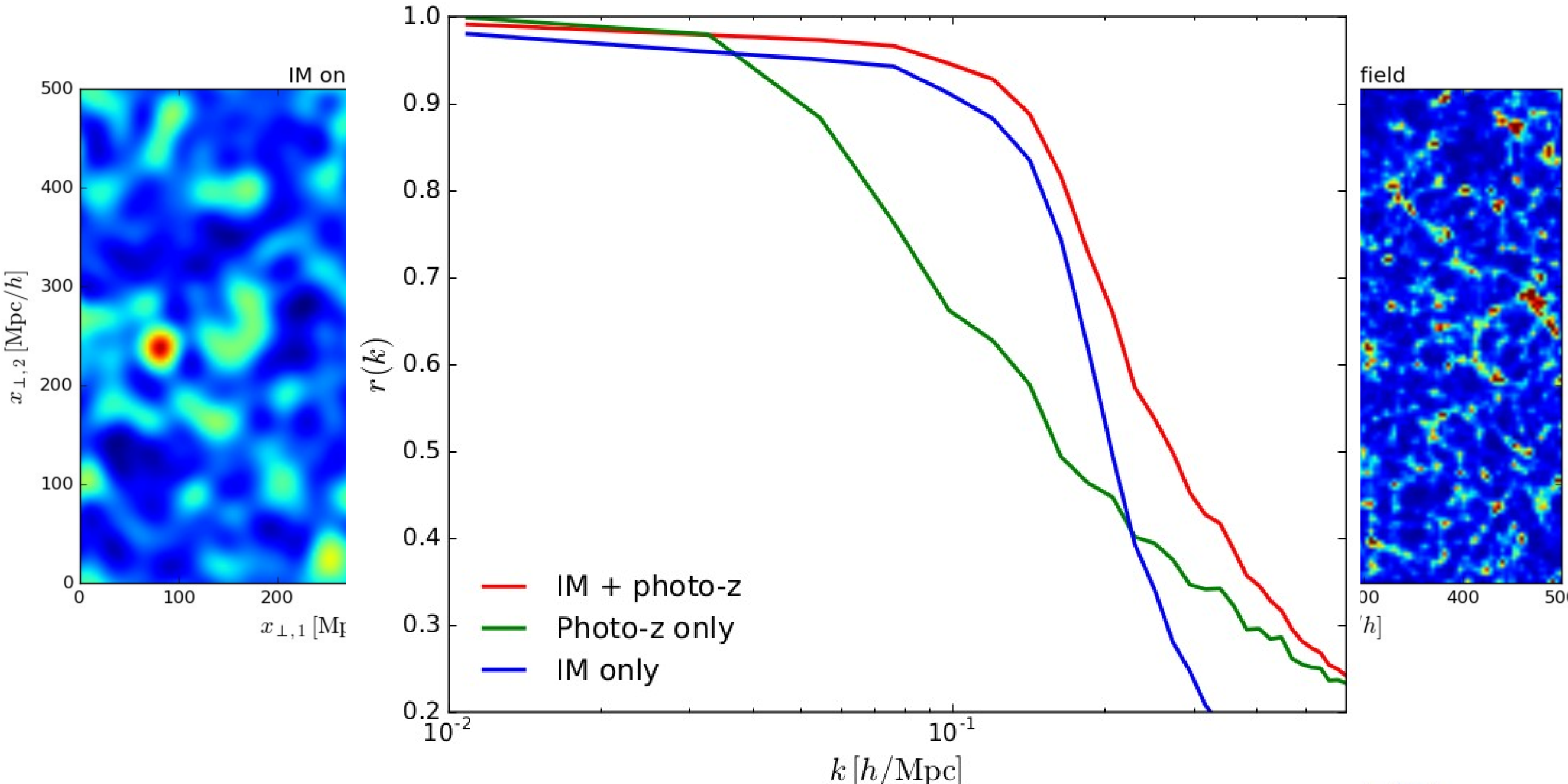

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Conclusions

- LSST and SKA will provide deep and wide observations of ~50% of the sky with an unprecedented frequency coverage.
- The possibilities for cross-correlations are exciting!
- Photometric surveys and IM experiments are highly complementary in terms of coverage of scales and tracer properties.
- Combined observations could improve current constraints on modified gravity by a factor 10.
- Taking advantage of the multi-tracer effect, the measurement of large-scale observables could be improved significantly (including a first detection of relativistic LSS effects).
- Cross-correlation with IM can help mitigate photo-z related systematics (e.g. clustering redshifts), especially at high redshifts.
- Foreground contamination in IM could also be mitigated by this synergy.
- Individual photo-z's can be improved upon using clustering information in a Bayesian setting.
  - Up to ~x10 improvement in individual photo-z's.
  - Clean sample: impervious to photo-z bias, ~30% better uncertainties
- Optimal recovery of the underlying density distribution

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Thanks!

Backup slides

Technical challenges: calibration

- Record signal as a function of time and frequency:
  - $I \sim G^*(\text{Foregrounds} + \text{Signal}) + B + N$

    Gain: it fluctuates!

    instrumental effects

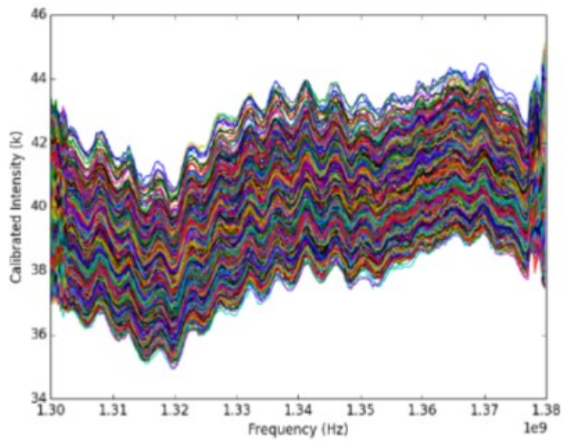
    Noise term

Credit: Mario Santos

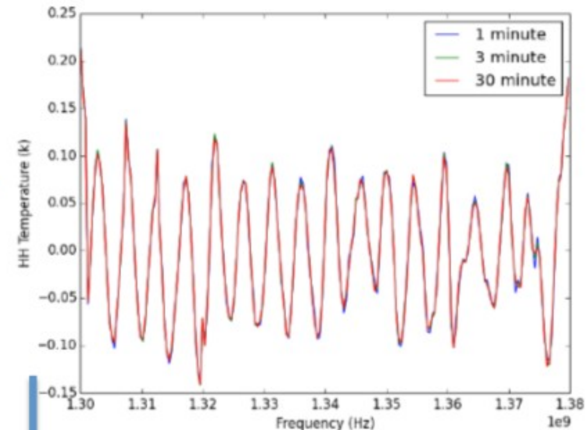
- But we also have high resolution imaging with the interferometer for each pointing…
- Main idea: use the interferometer data to calibrate the gains
- Need to deal with correlated noise (1/f noise): survey strategy? (mapmaking techniques)
- Concerns with instrument stability…
- Note: we are not looking for an absolute signal: “long wavelength” fluctuations in frequency and angle are OK…

Backup slides

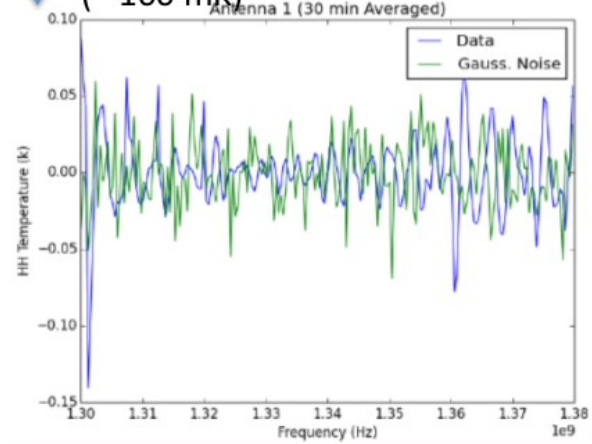
KAT7 foreground cleaning



Initial data. Drift scan. 1 dish. 30 min.
1 sec time stamps. 80 MHz band
(~ 40,000 mK)



After removing the smooth components – sinusoidal residual
(~ 100 mK)

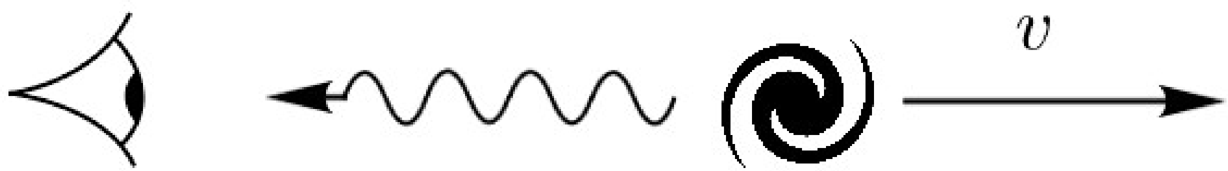


Fit a "sine wave" like template.
Final result "noise like" after 30 min. integration.
(~ 30 mK – noise/HI signal should be ~ 1 mK)

Credit: Mario Santos

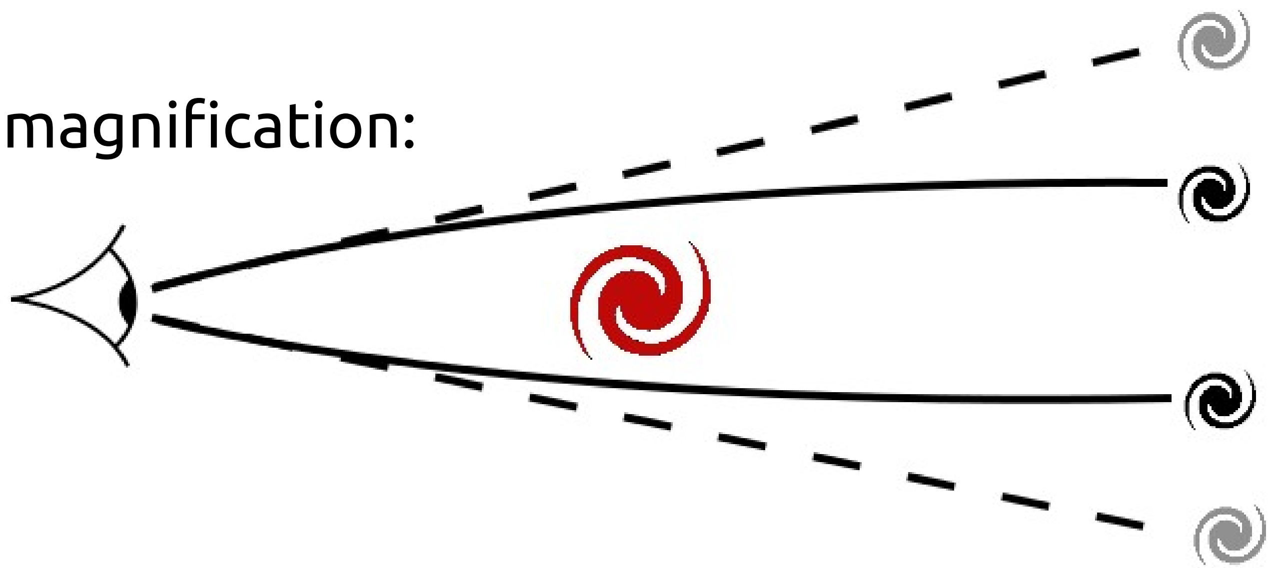
Backup slides

RSDs:



$$\delta z \propto v$$

Lensing magnification:



$$\delta\theta \propto \nabla_\theta \int dr\, \Phi$$

Sachs-Wolfe:

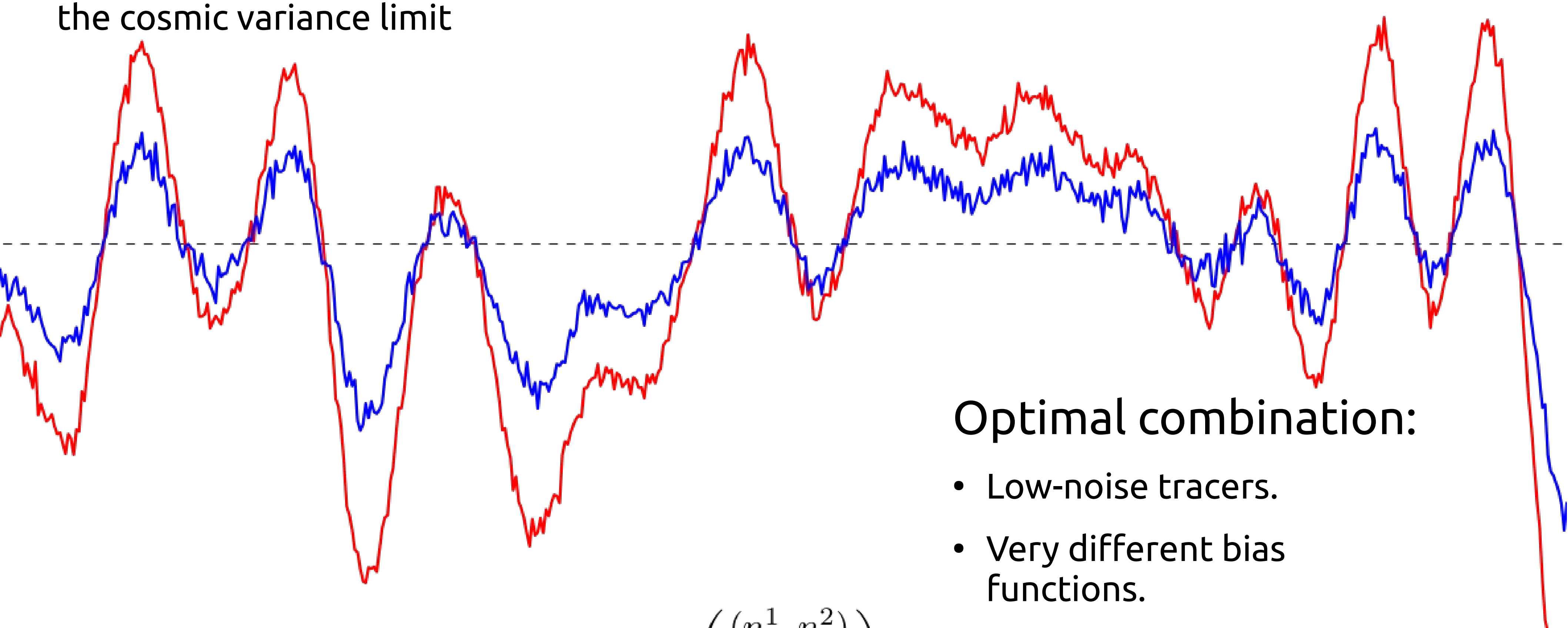
$$\begin{cases} \delta z \propto \Phi \\ \delta z \propto \int \dot{\Phi} \end{cases}$$

Challinor and Lewis, 1105.5292
Bonvin and Durrer, 1105.5280

Backup slides

For disjoint tracers deterministically related to the density field, terms proportional to the bias parameters can be measured below the cosmic variance limit

$$\delta^a_{\mathbf{k}} = b^a\,\delta_{\mathbf{k}} + n^a \longrightarrow \sigma\left(\frac{b^1}{b^2}\right) = \mathcal{O}(n^1, n^2)$$



Optimal combination:

- Low-noise tracers.
- Very different bias functions.
- E.g.: photometric survey, red vs. blue galaxies

$$\delta^a_{\mathbf{k}} = b^a\,\delta_{\mathbf{k}} + \epsilon f^a g_{\mathbf{k}} + n^a \longrightarrow \sigma(\epsilon) = \mathcal{O}\left(\frac{(n^1, n^2)}{f^1 - f^2}\right)$$

Seljak, 0807.1770